Sustainable Decision Support for Environmental Problems in Developing Countries: Applying Multi-Criteria Spatial Analysis on the Nicaragua Development Gateway niDG

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Abstract. The challenge of human development taking into account the social and economic background while protecting the environment confronts decision makers in government, local communities and development organizations. How can new technology for information and communication be applied to fulfill this task? This paper gives a review of decision support techniques and their requirements to achieve sustainable results. We propose an approach that combines analytical GIS with OLAP and data mining and show its capabilities as an effective instrument on the base of its application at real projects in Nicaragua.

1 Introduction

The number of natural catastrophes that harass the world raises over 700 each year shattering lives, destroying assets and disrupting communities across broad geographic zones [11]. Mainly affected are the regions of Asia and America, where most of the countries have a high poverty rate. Which consequences have those disasters for the developing countries? How to integrate economic and social factors in the planning process for prevention and recovering? And which instruments can support the effective request and application of development aid?

Trying to respond these questions implies the necessity of "knowledge systems", which can manipulate and present large amounts of complex data, taking into account local and regional aspects and the spatial and temporal distribution of influence factors. This process, known as exploration, means to extract meaning from data, discover structures, find patterns and derive causal relationships. Most of the currently used systems for decision-making tend to separate economic, social and environmental factors at the policy, planning and management levels. Focusing economic and political decision-making on environment and development by considering country specific conditions in terms of the Local Agenda 21, chap. 8.2 [13], demands a full integration of these factors and enables efficient and sustainable development.

The base of an exploration supporting system is an area-wide compilation of data, if possible, over a long period of time. To collect the data and to offer it up-to-date to a vast number of organisations, public investors and stakeholders requires a technical infrastructure and organized processes. The use of information and communication technologies (ICT) is increasingly acknowledged as a strategy to assist sustainable development. By contrast, the introduction of ICT without an adequate study of the applicability and the natural and social context can become useless or even counterproductive [14]. For instance, installing a telecenter in an urban zone with little or telecommunication infrastructure may sound like an improvement on the quality of life, but if the increasing cost for energy and networking can not be maintained, then the incentive fails. This means that an instrument that assists the choice of how and where ICT (and also non-ICT) projects should be applied is also indispensable for the sustainability of the projects.

To respond to the first questions and to facilitate the appropriate application of ICT we introduce a tool for spatial decision support, CommonGIS, and integrate it in an existing technical infrastructure provided by the organizations that realize the country gateway goals. This paper describes its usage for analyzing environmental problems in Nicaragua and for supporting decisions for technical and strategic planning.

2 Background

2.1 Facts about Nicaragua

Nicaragua is one of the least developed countries in Latin America. Over 5.2 Mio people live on 130.000 km^2, but the population density varies extremely: in Managua it reaches thousand or more people per km^2, in rural areas it may drop down to 2 or less per km^2. The distribution of the infrastructure, the per capita income and the level of education, just to mention some measures, is very inhomogeneous. Some regions in the east have no road connections with the west of the country. The country counts more than 600 volcanoes with high risks. Since 1973 150 earthquakes with more than 5 mb G have occurred. Nicaragua's balance of trade is negative though emigrants support their families with credit transfers. Dept service amounts to 35 % of the national budget. About 85 % of its population are poor with less than 1.5 $ income per capita and day leaving no room for extra consumption. In Nicaragua poverty is extreme. More than 30 % of the population suffers famine due to a lack of appropriate incomes. 54 % of it are younger than 20 years.

Functional illiteracy reaches 50 %. The average grade achieved in public schools corresponds to 4th grade of primary education. Though the number of students in public education almost doubled during the last 15 years, still about 28% of the respective age groups do not attend school at all. In contrast, there are about 11.000 university students in computing or related subjects and about 4.000 professionals with a university-degree. In rural areas access to a phone may be measured by walks of 8 or more hours – one way! In contrast, in Managua and other larges cities there are more than 500 telecenters with qualified personnel (university degree in computer science).

If such differences are not treated appropriately, they may cause serious conflicts. In Wiwili e.g., a municipality in the west, a sharp conflict arose when one part of the town got nearly all the aid after the hurricane Mitch while the other, on the opposite riverbank, got almost none. The conflict was solved by subdividing Wiwili into two municipalities each responsible for its negotiations with the government. Managua, the capital, is crossed by a dozen earth faults. Hence urban planning depends on spatially differentiated risks for the population. 100 meters of spatial distance may triple construction costs.

Installing a telecenter e.g. depends on the goals one has to reach: If there is a short-term need to refinance the investment and to accumulate stocks for further investment then the telecenter with Internet access has to be installed where the purchase power of the surrounding area will support such a center. This contrasts to a long-term strategy where one would seek to facilitate access to communication for poor rural farmers. Here a multipurpose communication center, which combines traditional phone services with digital services, might be more adequate. Here, most people have plenty of emerging needs, such as improving their housing and education. Telecommunications needs are not at the top of the list, so investment in Internet access has to bring *concrete* benefits, particularly in the short term. It is important to offer a vision for development to the users of a telecenter [8]. To achieve this vision, a telecenter needs appropriate local operators – like local non-governmental organizations, cooperatives or other community groups.

2.2 The Nicaragua Development Gateway

The Nicaragua Development Gateway niDG has been assumed by CADIN - Nicaraguan Chamber of Industry - and AIN - Internet Association of Nicaragua - since June 2001 by grant of the Development Gateway Foundation DGF (Worldbank Group)[1]. "The Nicaragua Development Gateway niDG-eNicaragua aims to increase effectiveness and impact of ICT as a means for the Development of Nicaragua within the framework of the National Development Plan, a long-term strategy proposed by the Nicaraguan Government to solve basic structural problems of Nicaragua."[2].

AIN is a non-profit association and affiliates private ISP (Institutes of technology) and all four public universities. Together they manage 80% of Internet traffic in Nicaragua. The niDG-program is implemented by the AIN project eNicaragua[3] and offers a portfolio of ICT competence centers, ICT projects and ICT document management systems. Just to mention some, the project ICT-Meter provides information access over an ICT infrastructure while ICT-MAP offers a broad spectrum of area-related socio-economic data.

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[1] http://www.dgfoundation.org, http://www.developmentgateway.org/, September, 2004
[2] http://www.developmentgateway.org/node/322831/interpage/index?iso=ni, September, 2004
[3] http://www.enicaragua.org.ni, September, 2004

3 Why Spatial Decision Support?

The introduction of the gateway shows the difficulties arising from trying to alleviate poverty and environment problems by means of information and communication technologies (ICTs) as envisaged in the 8^{th} Millenium Development Goal. In Nicaragua the presidential secretaries for strategic planning and coordination, the National Institute for Territorial Studies and the National Institute for Census and Statistics are in charge to monitor and evaluate the results of the Nicaraguan Poverty Reduction and Economic Growth Strategy, convened by Nicaragua and the donor community as part of the debt reduction of the Heavily Indebted Poor Countries HIPC. In most cases this task implies a spatio-temporal analysis of socio-economic and environmental data, not only a visualization of bare connectivity or availability of grid electricity e.g.

Actually lots of geo-referenced data are available in Nicaragua but they are managed by different institutions, using different formats and maps with different scales and projections, different levels of aggregation, and different zoning of regions. Hence, in Nicaragua as in many other places, Geographical Information Systems GIS have been introduced to present the complexity geographically. Yet most of these tools permit only an overlaid presentation of localized facts as in figure 1, or – when used as planning tools – of projected localized objectives and their constraints. To become an active part of the planning process, tools are needed that permit the *analysis* of different scenarios with data from different sources – what-if type of analysis – and the dynamic comparison of projected outcomes between different regions.

The Fraunhofer Institute for Autonomous Intelligent Systems AIS has started a project in cooperation with the Asociación Internet de Nicaragua AIN and its operating entity eNicaragua. AIS provides the analytical tool CommonGIS together with a pilot demonstrator. CommonGIS is a specialized geo-information system (GIS) that enables an efficient and highly interactive exploration and spatial analysis of attributed geographical data. It allows to visualize and manipulate spatially differentiated results. Its features are intuitive and easy to learn, even for less experienced users. CommonGIS is web-enabled, providing access to different entities via the internet. Employing CommonGIS one will reap the benefits of a longstanding experience with applications of this tool (and its predecessors) in Western Europe.

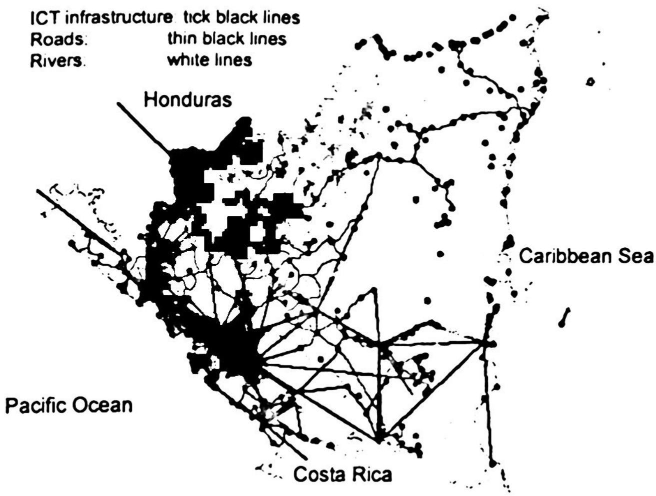

Fig.1. Nicaragua's uneven distribution of infrastructure: Main roads, town centers, and ICT infrastructure (phones, mobiles, television). (Data source: TELCOR Nicaragua)

3.1 Multidimensional View of Information

To handle big amounts of data for decision fast and easy decision making it is not recommended to work with the same structures as for on-line transaction processing (OLTP), traditionally supported by the operational databases. There, tasks are structured for isolated transactions. Consistency and recoverability of the database are critical. Transactional database are designed to reflect the operational semantics of known applications, and, in particular, to minimize concurrency conflicts. In contrast, the summarization and consolidation of data in data warehouses is targeted for decision support. High workloads arise with mostly ad hoc, complex queries to a huge number of records and a big amount of operations [7]. This kind of requests, where query performance and response times are more important than transaction throughput, is known as on-line analytical processing (OLAP) and assumes three components: the database, an operation server and the clients. The operation server executes the requests, aggregating and specialising the data on demand, and also has to ply with hierarchical structures for levels of granularity and missing data. The clients access the database through the server and present the data for exploration. The database should be modelled with multiple dimensions, which means, the properties of facts will be classified as dimensions or measures. Time, space and every independent variable are dimensions. They must describe the measures unambiguously. Some measures are not existent for specified dimension values, so they have to be interpolated or computed with predefined or ad hoc input.

To make the best use of spatial and temporal dimensions in decision making the analysis of hierarchical multidimensional data should be combined to the visual and analytical capabilities of a GIS. The coupling of OLAP and GIS technology is known as Spatial OLAP or SOLAP [6].

3.2 Using Data Mining for Decision Support

Once we have filled big data warehouses, how can we find concealed causal relationships that help us to answer important questions? Consider an illustrative problem: In some places in Nicaragua the concept of backyards was introduced in order to provide people with fresh vegetables. This concept failed somewhere, elsewhere it succeeded. Are there hidden reasons for this paradoxical result? Could we find an explanation through mining in the data on the socio-economic context? Furthermore, with respect to risk management we often find questions on the temporal relation between events.

Data mining is the partially automated search for hidden patterns in typically large and multi-dimensional databases. The results of data mining techniques are abstract behavior models that can be used to explain and predict consequences, e.g. to support risk management and mitigation of natural hazards.

So far, data mining and GIS have existed as two separate technologies. Recently, their integration has become attractive as various organizations possessing huge databases began to realize the potential of information hidden there. SPIN!, another product of AIS, integrates CommonGIS for interactive visual data exploration with data mining in a closely coupled, open, and extensible system [9, 10]. The data mining functionality is adapted for spatial data. A spatial database is used to execute the spatial queries generated by the analysis algorithms. The system combines data mining methods for spatial data such as multi-relational subgroup discovery, rule induction and spatial cluster analysis with the interactive functionality of visual data exploration, thus offering an integrated, distributed environment for spatial data analysis.

4 Applying CommonGIS in Nicaragua

4.1 Overview on CommonGIS

The combination of visualization and data analysis in CommonGIS empowers not just geographers and analysts to make full use of geographical information. CommonGIS provides a better basis for adequate decisions and later for their evaluation. CommonGIS makes geographic data, including time-series, interactively usable for authorities, enterprises, organizations or other people trained in using ICT, via intranet or internet. The automatic generation of thematic maps unburdens the user from complex map creation tasks. CommonGIS can be customized to be offered in a

Web environment as an interactive viewer of data and analysis results[4]. Equipped with laptop and beamer users are able to demonstrate online and interactively the analysis of geo-referenced data. Especially a functionally illiterate auditorium as can be met in many places in a least developed country like Nicaragua could have a realistic insight into statistical relations which could not be given through written text or endless tables. The auditorium could better understand its situation – *presupposed* the demonstration is mediated by trained people. The tool helps to discuss alternative solutions of planning questions:

- Where is the best place to locate a factory needing clean water, near roads, close to raw materials and electricity taking into account the environment?
- How to assess soil erosion and its impact on production?
- How to predict and prevent natural event or demographic migration? (CGIS 2004)

Translated into the philosophy of CommonGIS such tasks comply with the functionality of the tool [2-4] of which we give an incomplete overview:

- Effective multidimensional description of spatial objects: "How to characterize a set of attributes that influence space?"
- Multidimensional query and search for spatial objects: "Where to find a special type of space?"
- Multivariate spatial analysis (e.g. dominance analysis): "Where are regions with exceptional attribute properties in comparison to all other properties and regions?"
- Spatial hypothesis finding: "Is there a spatial/non-spatial relation between attributes?"
- Multicriteria decision support: "Where is the best region according to several weighted criteria, and how sensitive is the decision when criteria weights are changed?"
- Visual analysis of spatio-temporal data by using time-series: How a spatial pattern evolves over time, for instance the influence of hurricanes, the change of settlements and migration processes?

4.2 Data Mining and CommonGIS

The examples given above indicate the effective extraction of geographical knowledge from statistical data trough CommonGIS. SPIN! offers a platform to connect data mining to an analytical GIS like CommonGIS, adapting the data mining algorithms for spatial data. SPIN! links cartographic and non-cartographic displays together through simultaneous dynamic highlighting of the corresponding parts. As the user navigates in the list of spatial rules, the corresponding geographic objects in the map window are dynamically highlighted.

[4] http://www.commongis.com/html/viewlets/advertising/advertisingcgis_viewlet.html, September, 2004

With the simultaneous visualization of the results one can prepare non-trivial decisions. Decision makers may back up their intuitive insights by sound statistics, and automatically explore patterns in the data that are invisible to the eye because they live in high-dimensional spaces.

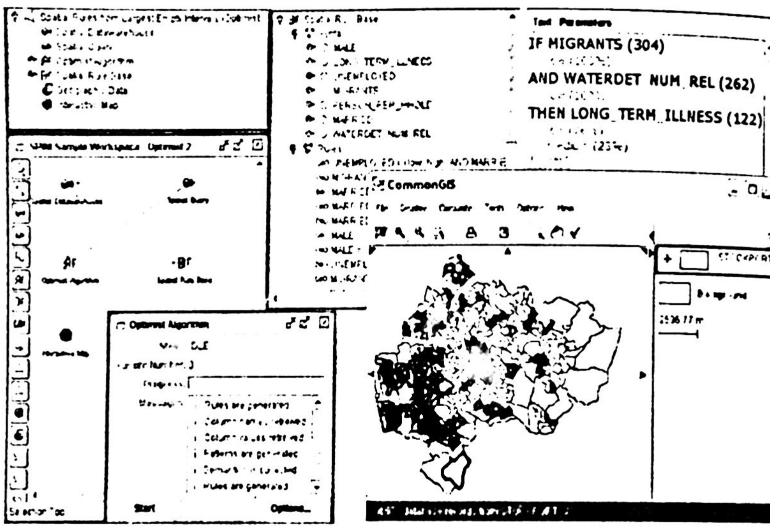

Fig. 2. Visualization of spatial rules: Map and other views in SPIN! are shown simultaneously and interactively

Figure 2 shows an analysis applied to UK 1991 census data for Stockport, a district in Greater Manchester, UK. The analysis was carried out at the level of enumeration districts (the lowest level of aggregation) characterized by such attributes like persons and cars per household, migration, long-term illness, and unemployment. Spatial data were given as coordinates and borders of objects, like enumeration districts, water, roads, streets, railways, and bus stops. In the shown example the spatial rule induction algorithm [12] finds a relationship between districts with high migration rate and high long-term illness.

In chapter 3.2 we referred to the paradoxical result for the backyards attempt in Nicaragua. This could be analyzed in a similar way. A tool like SPIN! supports decision makers to understand the efficiency of development projects and the reasons for success and failure.

CommonGIS also offers a data mining interface to the public domain data mining system Weka [16], allowing the use of data mining algorithms like cluster analysis for attributes and grids (field data) [1,5].

4.3 Developing a Pilot for Demonstrations

The first steps of the project concern a few of the mentioned aspects only. AIS had to inspect a lot of files delivered by the partner in Nicaragua. The huge amount of files was due to a high redundancy of the scattered, inconsistent and mostly undocumented data (different zoning, different ordering, varying data types and projections). The project implements a "demonstrator" which may serve as a proof-of-concept for those state agencies in Nicaragua that already have a stock of geo-referenced data, yet do not use any analytic or visual exploratory GIS-based tools.

The demonstrator bundles some of the given data as "projects" in CommonGIS, namely:

- Geo-data like maps of Nicaragua, the zoning in regions and municipalities; rivers, roads, volcanoes, earthquake epicenters; average rainfall & temperature; telecommunication lines and nodes, television lines and nodes.
- Attribute data like population (1995), poor, extreme poor; communication capacity & users; voters (1996), invalid votes, resulting votes; risk of volcanoes (high/medium); intensity, date & location of earthquakes; technical data on telecommunication facilities.

Some of these data allow only overlay visualization as in figure 1. Others are analyzed using the features of CommonGIS as shown in the examples of figures 3 to 6. There, we first search for a spatial hypothesis explaining the distribution of poverty in Nicaragua (< 1.5 $ per capita and day). CommonGIS computes the percentage of poor with respect to the population. Figure 3 shows the result as a "dynamic classification" where one assigns interactively value classes to value intervals, shown on the dot plot diagram in the upper part of the right-hand manipulation window. One sees the value distribution together with the (colored) class breaks. CommonGIS automatically distributes the value classes according to the value distribution with least information loss; the user sees a thematic map: Poverty is unevenly distributed from the west to the poorer east (the poorer the region, the darker its color) (Data source: TELCOR). In general, the Nicaraguan cordilleras and the east coast are the poorest, Managua is the richest zone. Some east coast regions are exceptionally less poor than the typical east cost. Figure 1 shows that in these regions (Puerto Cabezas, Bonanza, Rosita) a communication infrastructure is not highly developed.

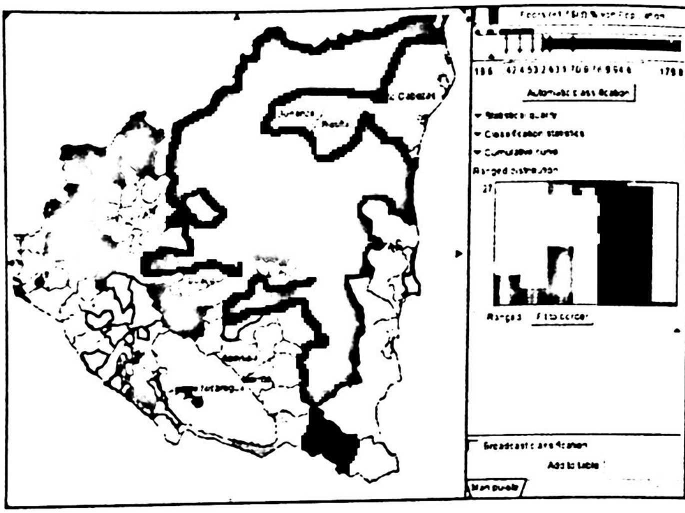

Fig. 3. Analysis of poverty distribution in Nicaragua

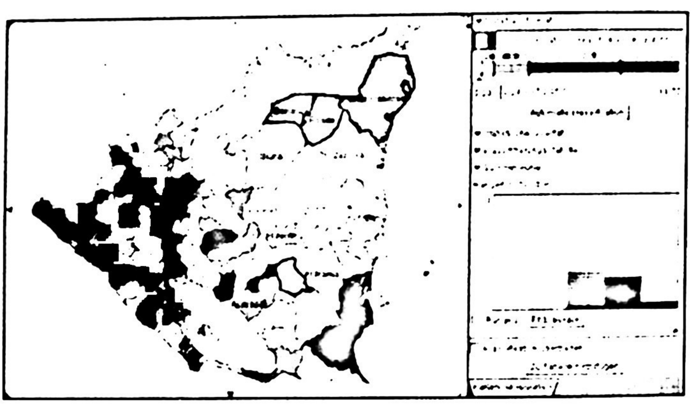

Fig. 4. Analysis of communication capacity distribution in Nicaragua

Is this observation significant? Figure 4 shows in a second window the distribution of communication capacity (the darker the color, the higher the capacity) which is similar to the poverty distribution: the mentioned east coast areas have an exceptionally high communication capacity. Does a statistical relation between infrastructure and poverty exist throughout Nicaragua? Can one find exceptions from this rule? How to detect these outliers? Where are they on the map? The interactive linking and brushing technique of CommonGIS helps to answer these questions. Figure 5 shows a correlation diagram of the attributes "poor in % of population" and "communication capacity". There is a medium negative correlation coefficient (-0.56) with some outliers highlighted (here as black circles) by mouse click. The interactive display technique immediately highlights all corresponding regions on the map in figure 3. Managua itself is an outlier to this relation. It has high poverty in relation to its infrastructural equipment. The histogram of the right-hand manipulation window in figure 3 shows most of these outliers in regions with middle or low poverty. They are located around the Lake Nicaragua. (Data source: TELCOR)

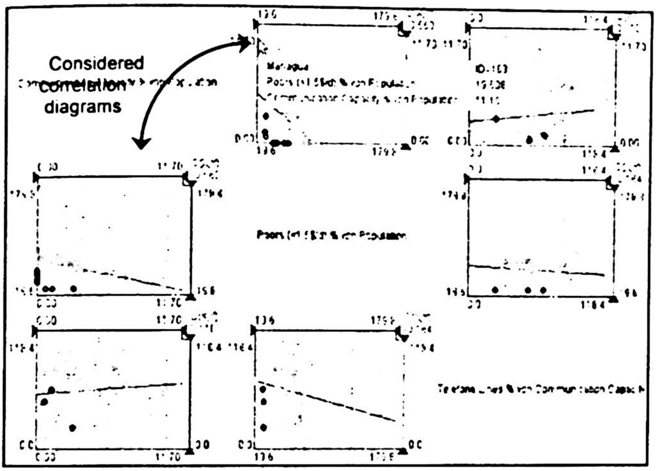

Fig. 5. Correlation between poverty and communication capacity

In a third example we use again multidimensional analysis. Figure 6 shows in the left the result of the 1996 election. The conservative PC won very few regions (medium grey), the liberal party PLC dominates the election results. Small parties did not win any region. The mountainous regions, some urban regions and the North East were won by the sandinista FSLN. What can be discovered from the electoral statistics?

CommonGIS can classify regions by dominant attributes, which are statistically outstanding attribute characteristics compared to all other attributes (by mean, median, quantiles or standard deviation e.g.). Figure 5 shows on the right an interactive dominance map of the electoral statistics. Here, median-quantile dominance was calculated over the number of votes for the 3 major parties plus "others" in each region. The histogram on the right shows, that those regions where the PC dominates are the most frequent (white), even though they did not win any of these regions. The PC does not show any spatial pattern except around the lake Nicaragua, were it clusters. The mountainous regions in the North did vote mostly for the FSLN and the PLC. The most striking spatial pattern is the distribution of minor party voters ("others", dark), which is the second most frequent dominance class. Obviously in the Eastern poor parts of Nicaragua, people vote exceptionally frequent for minor parties in comparison to all other regions.

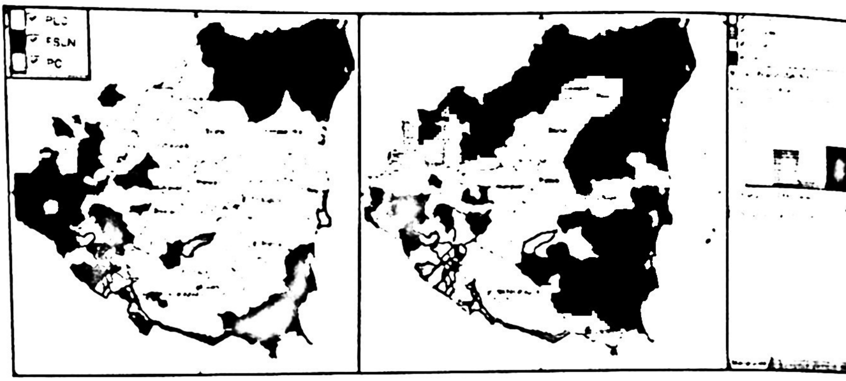

Fig. 6. *Left*: Winners of the 1996 election. *Right*: Interactive dominance classification of the 1996 election

4.4 Introducing OLAP to CommonGIS

While in OLAP warehouses space is just another dimension, it is the distinguished concept in every geographic information system (GIS). That means, the spatial dimension receives special treatment and offers special types of interaction. In order to move along a spatial hierarchy, the user would not click on a pull-down menu or button, but would simply zoom into or out-of a map. To this end the geographic layers corresponding to the successive spatial levels should have successive ranges of scales and be replaced as the user zooms in or out. Moreover, thematic visualizations should automatically be reconstructed at coarser or finer layers.

To achieve this, CommonGIS must automatically aggregate or distribute the values of all attributes involved in the current visualizations. These may be measures from one or more cubes, but also attributes from other data sources which do not exist at other levels. For such non-measures, CommonGIS cannot delegate computation to the warehouse, but it must compute the necessary aggregations or distributions. To inspect a cross-classification of communication instruments with poverty rate over distinct regions, districts and municipalities, CommonGIS should automatically recomputed the cross-classification for each spatial detail level. The user would only intervene in order to change the chosen aggregation operators: e.g. sums for communication instrument and average for poverty rate.

The common denominator between the data models of CommonGIS and OLAP is the concept of parameterized attributes, or dimensional measures, respectively. However, since the tables in CommonGIS have rows for geographic objects, CommonGIS can only handle measures with a spatial parameter. On the other hand, cube measures are always quantitative, while CommonGIS can handle qualitative

attributes. This qualitative attributes can change their type by aggregation. At a higher level they can become Boolean (exist and do not exist) or quantitative. An example is the analysis of which natural catastrophes mainly ravage a town. For the region the user may not just want to se the computed main disaster, but also the number of towns where the event prevailed.
CommonGIS does not support hierarchical parameters yet. To handle hierarchies of non-spatial dimensions the user interface of CommonGIS will include buttons that let. the user independently switch the level of each parameter hierarchy. Additionally the user will be able to choose or change the aggregation operator for each attribute. The present version of CommonGIS can already compute aggregations, though only at one level. For instance, CommonGIS can aggregate the communication capabilities of regions, by summing up over all communication tools (cable-telephone, mobile phones, internet-access, etc.) or over spatial entities as towns, regions and municipalities, yielding an attribute for e.g. the sum, average, etc. of all communication instruments or for each instrument at coarser spatial parameters.

There are many other important aspects to take into account. First how to handle class borders, if the user made a restriction of the viewing data, and then changes the hierarchy level. Further, how to re-compute dynamic attributes, such as rankings, which are dependent on other attributes and its weight. At least CommonGIS has to manage filters and selections while the user moves up or down the spatial hierarchy.

Regarding this premises, CommonGIS is being extended to become a Spatial OLAP Client [15].

4.5 Using CommonGIS in the Project of Continuous Monitoring of ICT Indicators

An ongoing target to use the CommonGIS as SOLAP-tool is on the project of continuous monitoring of indicators for Information and Communication Technologies (ICT). This project pursues the definition of statistical parameters both ICT as non-ICT and their annual recompilation over a number of countries in Latin America to define indicators of its use. The computed indicators should be automatically updated when the statistical parameters are being renewal.

This system will allow handling statistical data and indicators about penetration and use of ICT combined with socioeconomic data of the related countries, their municipalities, even their regions. The analysis and monitoring can then be done on different detail levels of space, time and indicator parameter. Periodical mechanisms of recompilation and loading of date will grant the up-to-dateness of information.

The project intends to be a bridge for collaboration and interchange on ICT-projects and to promote a synergy of the actors (stakeholders). This would cause an improvement on the efficiency of the projects implicating a sustainable success at the development process of the countries.

The realisation will be structured into two phases: A conceptual phase for defining the parameters, designing the database and implementing the recompilation, updating and aggregation mechanisms for the data warehouse, to be accessed via OLAP and the execution phase where the data will be loaded and presented over the web. CommonGIS suits this issue as front-end offering an analytical tool to monitor and explore the data as well as a communication tool, presenting scores, hypothesis and intermediary results over the web to the involved actors. It will allow the navigation through the different granularity levels over space and time facilitating forecasting of tendencies and supervision of projects.

5 Results and Outgoing Goals

On the focus of achieving sustainable decision support for environmental problems in developing countries we summarized techniques and requirements to be fulfilled and applied at development projects. This paper has presented an approach of use ICT for the challenge of improving the conditions of development countries taking into account environment, economic and social tasks as well as their examination over periods of time and different spatial levels.

CommonGIS, an analysis tool for decision support that joins GIS, statistics and data mining techniques, offers an instrument to be used at environmental projects, allowing the distributed publication of statistical data in the internet by dynamically and automatically developed maps as well as environmental monitoring, interactive analysis and publication of environmental data and simulation results. The application of CommonGIS, for tangible development tasks in Nicaragua shows a proposal of how to introduce ICT meaningful on sustainable development projects.

AIS is extending CommonGIS to be ready to use as SOLAP client on current and further collaboration projects.

The global network established by the Country Development Gateways met in Bonn in June 2004. AIS presented the CommonGIS demonstrator for Nicaragua, which arouse big interest in the representatives of countries with similar problems (Bolivia, Guatemala, Kenya, Mongolia, Palestine, Romania, Rwanda, Venezuela and Vietnam).

Currently the GTZ (Deutsche Gesellschaft für Technische Zusammenarbeit), the major German enterprise of international cooperation for sustainable development with worldwide operations, has agree to support the project *ImpCommonGIS*, on which CommonGIS will be customized, people will be trained and methods of resolutions will be provided in form of CommonGIS-projects to be use by eNicaragua/AIN. These applications will map the digital divide inside the country, showing the efficiency of the tool and training at the same time the people during its use.

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